

# Macroscopic Relationships among Latent Heating, Precipitation, Organized Convection and the Environment

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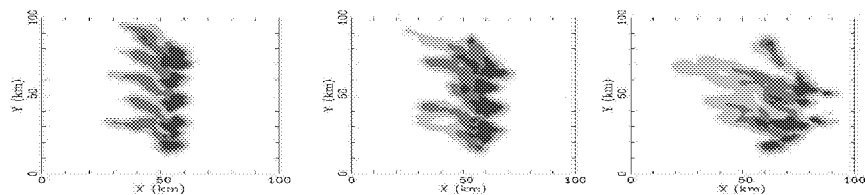
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## Research Accomplishments NAG5-7742

### *Simulation of TRMM-LBA convection*

Three-dimensional CRM simulations were conducted to examine the squall line observed on 26 January, 1999 from the TRMM-LBA field campaign. The computational domain was 600km x 180km x 20km with a horizontal resolution of 1 km and a vertical resolution of 200m. The CRM was initialized from the Abracos Hill and Rebio soundings. Convection was initiated by a surface-based and NW-SE oriented cold pool over a region 60km in the y-direction and 30km wide in the x-direction. The cold pool temperature perturbation is a maximum of -6K at the surface, decreasing linearly to zero at 3km. The simulated convection is in the form of a NW-SE band that moves toward the southwest at a speed of 8 m/s, and is generally comparable to radar observations.

### Numerical simulation



### S-Pol radar



20:00Z

20:34Z

21:56Z

*Figure 2. TRMM-LBA Feb. 23 quasi-stationary convective band. Uppermost plates show the simulated evolution, lowermost plates the radar-derived evolution*

A different regime of organization is the quasi-stationary convective band observed on 23 February 1999. Quasi-stationary bands are typically more difficult to realize than squall lines probably because of the more complex convection initiation process. We simulated this system in a 3-D computational domain of the same dimensions and resolution as the 26 January case. The CRM was initialized using the Abracos Hill sounding on 23 February at 18Z. A set of five-surface-based, N-S oriented and 1-km-deep, 5-km radius, and 1.5K-amplitude heating perturbations successfully initiated convection. Figure 2 compares the radar observations of the evolution of the quasi-stationary band with the simulation. We are preparing a paper on the above results.

### *Multi-day simulation of cloud systems in SCSMEX*

In long-term CRM simulations associated with field-experiments, the large-scale forcing is specified. A preliminary simulation has been completed using evolving large-scale forcing provided by Johnson and Ciesielski (2001). Figure 3a shows comparisons between the precipitation from this simulation, the TRMM product and GPCP. The space-time diagram in Fig. 3b shows the eastward-propagating precipitating cloud systems. Note that the GPCP and TRMM observations do not agree, and nor do they agree with the simulation, apart from the first two days and days 4-6. But until more accurate large-scale forcing is available (being prepared by Richard Johnson CSU) it is not possible to be definitive regarding the latter point. New simulations will be done once the improved large-scale forcing is available. We will also conduct three-dimensional CRM simulations, and mesoscale resolution simulations (i.e., the latter two models in the modeling hierarchy defined below). We will prepare a paper on the SCSMEX results.

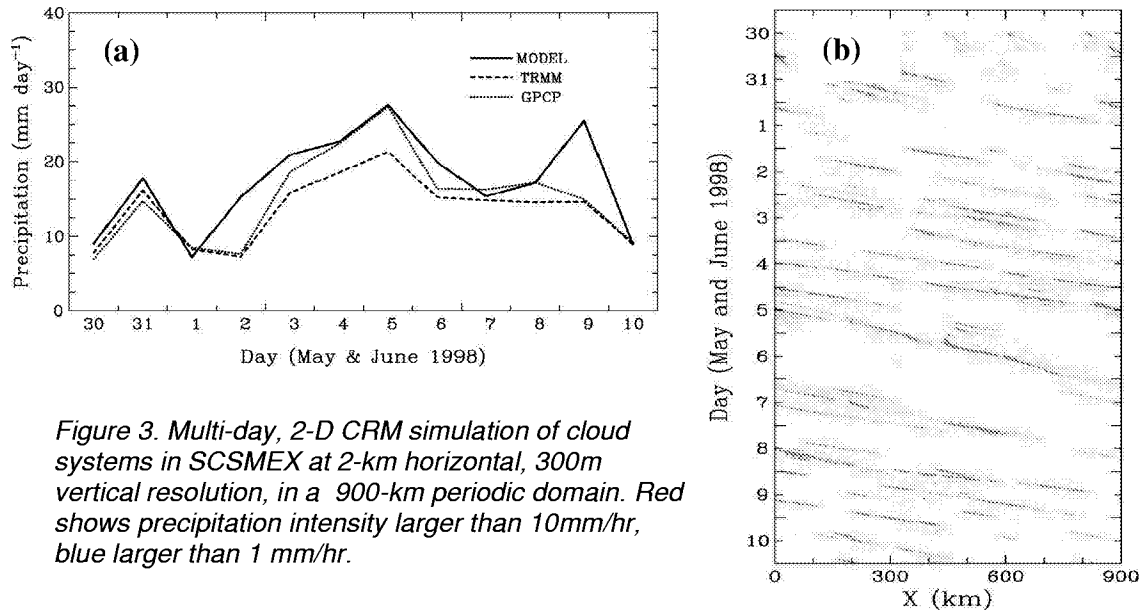


Figure 3. Multi-day, 2-D CRM simulation of cloud systems in SCSMEX at 2-km horizontal, 300m vertical resolution, in a 900-km periodic domain. Red shows precipitation intensity larger than 10mm/hr, blue larger than 1 mm/hr.

## Hierarchical modeling

Our hierarchical modeling methodology is three-pronged: i) cloud-resolving resolution ( $\sim 1$  km); ii) simulations that treat convection explicitly at mesoscale resolution ( $\sim 10$  km); and iii) simulations that apply parameterized convection at mesoscale resolution. Because the same non-hydrostatic code is used in all three of these models, they are fully consistent, which is not the case were the CRM embedded in a hydrostatic model. The Kain-Fritsch (1993) convective parameterization was examined using two-dimensional realizations of cloud systems observed during the period 19-26 December 1992 in TOGA COARE, and 3-D simulations of convection over the eastern tropical Atlantic (Fig. 4).

We found the following shortcomings in the convective parameterization: i) Overly deeper convection and more extensive cirrus than the CRM simulation, due to excessive detrainment of condensate and water vapor. The simulations are sensitive to the magnitude of moisture feedback from the convective parameterization to the grid scale yet not to whether it is in vapor or condensate form. ii) The parameterized overshoot-generated cooling around cloud tops is too strong, resulting in a cold bias near the tropopause. iii) Over-prediction of lower-level moisture was partially attributed to the parameterized downdrafts being too moist. These deficiencies stem from the single-plume model used in the parameterization scheme, which cannot adequately represent the trimodal convection (i.e., cumulonimbus, cumulus congestus, and shallow convection) realized in the CRM and also observed (see Liu *et al.* 2001b).

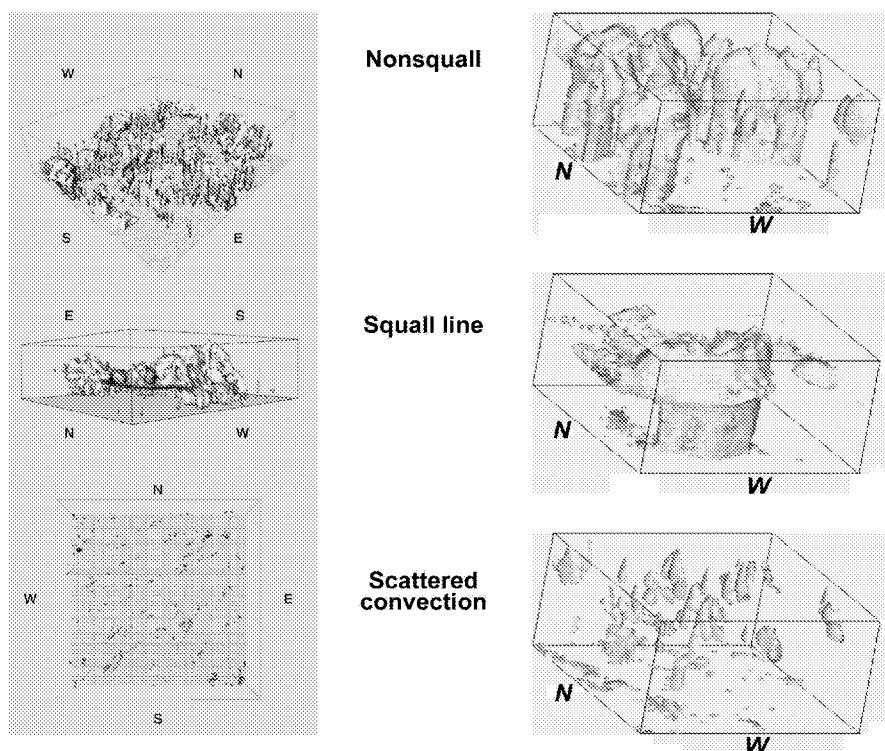
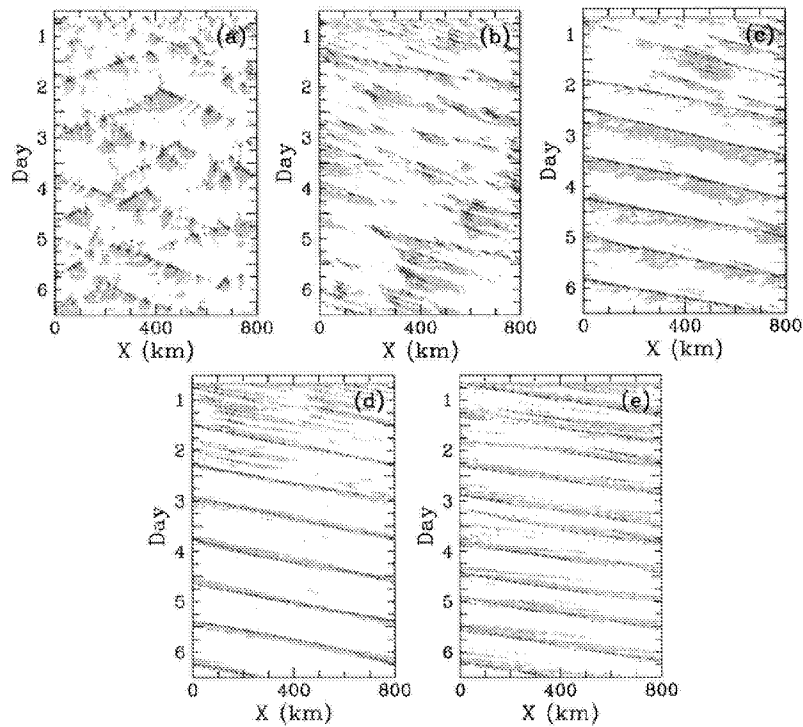


Figure 4. Snapshots showing the structure of three simulated convective cloud systems over the tropical eastern Atlantic. These distinct regimes evolved spontaneously as the large-scale vertical shear and dynamical forcing evolved, evincing the powerful controlling effect of wind shear. Leftmost plates are explicit realizations from the CRM simulation (2-km grid length), rightmost the corresponding structures obtained by applying the Kain-Fritsch parameterization in the hierarchical model with a 15-km grid length. [From Liu *et al.* (2001a)]

### *Idealized cumulus ensembles in shear flow*

A systematic numerical investigation by Liu and Moncrieff (2001) examined the role of ambient shear on the structural and transport properties of tropical cumulus ensembles maintained by CAPE generated by constant surface fluxes of temperature and moisture and large-scale advective cooling and moistening. The effects of five distinct idealized wind profiles on the organization of convection, and quantities relevant to the parameterization of convection and convectively generated clouds, are examined in a series of 6-day two-dimensional cloud-resolving simulations (Fig. 5). Lower-tropospheric shear affects the mesoscale organization of convection through interaction with evaporatively driven downdraft outflows (convective triggering), while shear in mid-to-upper levels determines the amount of stratiform cloud and whether the convective transport of momentum is upgradient or downgradient. Shear significantly affects the convective heating and drying, momentum transport, mass fluxes and cloud fraction. Sensitivity is strongest if the forcing is weak. The effects of shear on convective momentum transport and cloud fraction are large enough to be significant if included in parameterizations for climate models. This work was published in Liu and Moncrieff (2001).



*Figure 5. Simulated organization of convection in different mean flow regimes illustrates as a space-time plot of the precipitation rate. a) no mean flow; b) constant westerly flow of 6m/s, c) jet-like flow, d) strong low-level westerly shear but no shear aloft, and e) strong low-level westerly shear and weaker westerly shear aloft. The light and dark shading show precipitation rates larger than 1 and 10 mm/h, respectively. [From Liu and Moncrieff (2001)].*

The Principal Investigator advocated the choice of TRMM LBA convection cases for a model intercomparison study in GCSS Working Group 4. He is also an advocate for cloud system modeling in the proposed Global Precipitation Mission (GPM). It is clear that in a few years time global measurements will be essential to fully evaluate multiscale cloud system models, as well as the more detailed data sets available from field experiments. He contributed strongly to TRMM Workshops in Salt Lake City in 1999, at NASA Goddard in 2000, and is local organizer for the TRMM Latent Heating Workshop held at NCAR, October 10-11, 2001.